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RESEARCH MEMORANDUM

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EFFECTS ON ADJACENT SURFACES FROM THE FIRING OF ROCKET JETS

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NATIONAL ADVISORY COMMITTEE
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RESEARCH MEMORANDUM

EFFECTS ON ADJACENT SURFACES FROM THE FIRING OF ROCKET JETS

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SUMMARY

This paper is a preliminary and brief account of some research currently being conducted to determine the jet effects on adjacent surfaces from the firing of rocket jets. Measurements of jet-effect pressures on a flat plate as well as shadowgraphs are presented that were obtained when a rocket jet at a Mach number of 3 was exhausted downstream and upstream into free-stream flow at a Mach number of 2 located from 2 to 4.7 rocket-jet-exit diameters from the plate. The jet effects on the flat plate with the rocket jet exhausting downstream are of the same order of magnitude as those previously obtained from sonic exits with a total pressure 10 times lower. A maximum pressure coefficient on the plate of 1.35 was obtained when the rocket jet was exhausted upstream at 2 rocket-jet-exit diameters below the plate, and an integration of the measured jet-effect pressures at this position resulted in a normal force on the plate equal to 2.3 times the thrust output of the rocket jet.

INTRODUCTION

During the past few years the use of air-to-air rocket-propelled missiles for supersonic aircraft has become prominent. Also, it is reasonable to expect that, in the future, large-sized aircraft will be used as platforms for the launching of large-sized guided rocket-propelled missiles. These missiles might be fired not only forward but also rearward and sideways. It is important, then, to know the short-duration loads on adjacent wings and body surfaces of the aircraft from the rocket jet of the missile. Therefore, in the preflight jet of the Langley Pilotless Aircraft Research Station at Wallops Island, Va., a testing program has been initiated to determine the jet effects on adjacent surfaces from high-pressure short-duration rocket jets exhausting downstream, upstream, and normal to the free-stream flow. Up to the present time only preliminary tests from rocket jets firing downstream and upstream at a Mach number of 2 have been completed. The results from some of these tests are discussed in this paper.

SYMBOLS

C_p	pressure coefficient, $\frac{p_w - p_\infty}{q_\infty}$
d_j	diameter of rocket-jet exit
F_N	normal force
M_j	Mach number at exit of rocket jet
M_∞	free-stream Mach number
p_j	static pressure at exit of rocket jet
$p_{t,j}$	total pressure at exit of rocket jet
p_w	measured static pressure on plate
p_∞	free-stream static pressure
q_∞	free-stream dynamic pressure, $\frac{\gamma}{2} p_\infty M_\infty^2$
x	chordwise distance on plate
y	spanwise distance on plate
γ	ratio of specific heats (1.4 for air)

APPARATUS

Presented in figure 1 is a sketch of the test setup showing the location of a rocket-jet exit having a Mach number 3 nozzle below a flat plate at the exit of the blowdown tunnel having a Mach number 2 nozzle. Also shown in the figure is the relation of the rocket-jet exit relative to the flat plate for the four test positions that are discussed in this paper. These positions are for one rocket jet exhausting downstream that is located at $3.4d_j$ below the plate and $6.5d_j$ from the end of the plate and for three rocket jets exhausting upstream at 2, 3.4, and $4.7d_j$ below the plate, all of which were located at $0.74d_j$ upstream from the end of the plate. These upstream firing positions are henceforth referred to

as positions A, B, and C, respectively. The rocket-jet variation of total pressure with time was similar during each of the tests. The actual total firing time of the rocket jet was approximately 0.6 second with the rocket jets exhausting at a total pressure of approximately 1,000 pounds per square inch during the first 0.3 second and then reducing to zero pressure during the remaining 0.3 second. The data as presented in this paper were taken with the rocket jet exhausting at a total pressure of approximately 1,000 pounds per square inch.

INSTRUMENTATION

The location on the flat plate of 47 static-pressure orifices relative to the rocket-jet exits is shown in figure 2 as well as the area on the plate integrated to obtain the jet-effect normal load. As can be seen in this figure, the plate was pressure surveyed on only one side of the rocket-jet center line.

RESULTS AND DISCUSSION

Presented in figure 3 is the rocket-jet-off and rocket-jet-on center-line pressure distribution on the flat plate plotted over the jet-effect shock pattern that was obtained from shadowgraphs with the rocket jet exhausting downstream at $p_{t,j}/p_\infty = 68$ and $p_j/p_\infty = 2.1$. The shadowgraphs revealed the now-familiar two-shock jet-effect pattern that is obtained with a sonic turbojet exit. These two shocks are commonly called the exit shock and the jet shock. The maximum pressure coefficient of approximately 0.1 that was obtained directly behind the intersection on the plate of the exit shock is about the same that would be obtained from a sonic turbojet exit at $p_j/p_\infty = 3$ and $p_{t,j}/p_\infty = 6$.

Figure 4, which presents a typical shadowgraph with the rocket jet exhausting upstream at position A, shows a bow shock, upstream from the rocket-jet exit, standing in front of the maximum penetration of the rocket-jet exhaust which is burning. This bow shock is strong enough at the intersection with the plate to cause separation of the plate boundary layer. Figure 5, which presents a typical shadowgraph at position C, shows a bow shock, upstream from the rocket-jet exit, standing in front of the maximum penetration of the rocket-jet exhaust. This bow shock at position C is farther upstream from the rocket-jet exit than the one obtained at position A; also, it has a greater curvature from its normal position at the center, and at the intersection point on the plate it is reflected.

Presented in figure 6 is the rocket-jet-off center-line pressure distribution as well as the rocket-jet-on center-line pressure distribution on the plate, and presented in figure 7 is the rocket-jet-on spanwise pressure distribution obtained at position A. When the rocket jet was fired at this position, figure 6 shows that the bow shock in front of the rocket-jet exit with the rocket jet off moved from a position approximately $0.7d_j$ to a position $2d_j$ to $3d_j$ upstream from the exit. This bow shock stands in front of the most forward pentration of the rocket-jet fuel-rich exhaust which is mixing with the incoming free-stream air and is burning in the zone designated as the mixing zone. At the same time, this bow shock induced separation of the plate boundary layer upstream of its intersection on the plate. The resulting initial rise in the rocket-jet-on center-line pressure distribution on the plate is similar to that obtained in references 1 and 2 from the separation of a turbulent boundary layer by the step technique; the first peak value of 0.35 as obtained in this test agrees very favorably with the step-technique value obtained in reference 1 on a flat plate at $M_\infty = 2$. Also, as illustrated in reference 2, the overall pressure rise for incipient separation can be considerably greater than the first peak pressure rise. In this test the overall pressure rise resulted in a maximum pressure coefficient of 1.35, which is 85 percent of the pressure coefficient that might be obtained directly behind a normal shock. This maximum pressure coefficient is reduced rapidly as the spanwise distance is increased in figure 7 as would be expected from the intersection of a bow shock and a flat plate, whereas the first peak value is essentially constant with the same increase in spanwise distance. A normal force on the plate of 2.3 times the rocket-jet thrust output was obtained at this position of $2d_j$ below the plate by integrating the pressure field that was measured on one side of the rocket-jet center line and multiplying the result by 2 on the assumption that the pressure distribution on the opposite side of the rocket-jet center line was the same.

In figures 8 and 9 is shown the center-line and spanwise pressure distribution on the plate with the rocket jet exhausting upstream at position C. When the rocket jet was fired at this position, the bow shock in front of the rocket-jet exit with the rocket jet off did not intersect the plate at this position and moved from approximately $0.7d_j$ to approximately $9d_j$ upstream from the exit. This large upstream movement of the bow shock resulted in the bow shock intersecting the plate upstream of the pressure-orifice field. A pressure coefficient of approximately 0.2 was obtained at the most forward orifice location, and this value gradually reduced on the plate in the downstream direction as well as in the spanwise direction.

CONCLUSIONS

An investigation is being made to determine the effects on adjacent surfaces from the firing of rocket jets. The following conclusions were obtained from observations of jet-effect pressures measured on a flat plate in conjunction with shadowgraphs when a rocket jet at a Mach number of 3 was exhausted downstream and upstream into free-stream flow at a Mach number of 2:

1. The jet effects on the flat plate with the rocket jet exhausting downstream are of the same order of magnitude as those previously obtained from sonic exits with a total pressure 10 times lower.

2. A maximum pressure coefficient on the plate of 1.35 was obtained when the rocket jet was exhausted upstream at two rocket-jet-exit diameters below the plate.

3. An integration of the measured jet-effect pressures on the plate with the rocket jet located at 2 rocket-jet-exit diameters below the plate resulted in a normal force on the plate equal to 2.3 times the thrust output of the rocket jet.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 5, 1957.

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2. Chapman, Dean R., Kuehn, Donald M., and Larson, Howard K.: Preliminary Report on a Study of Separated Flows in Supersonic and Subsonic Streams. NACA RM A55L14, 1956.

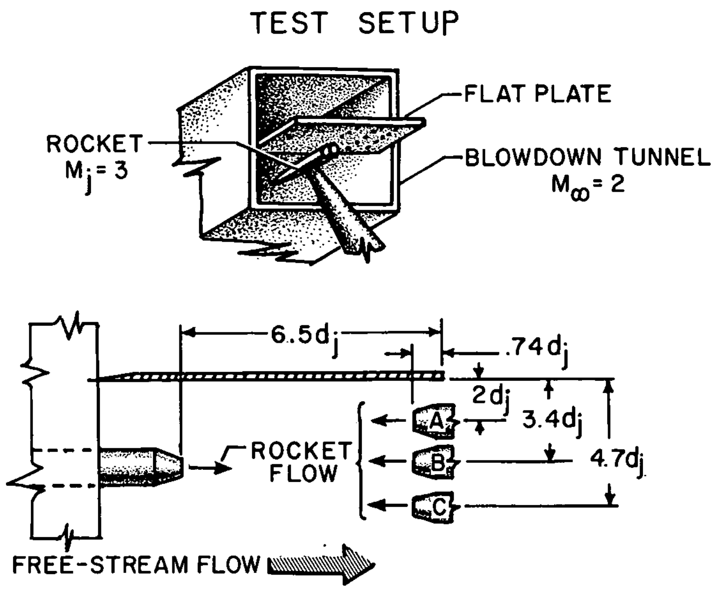

Figure 1

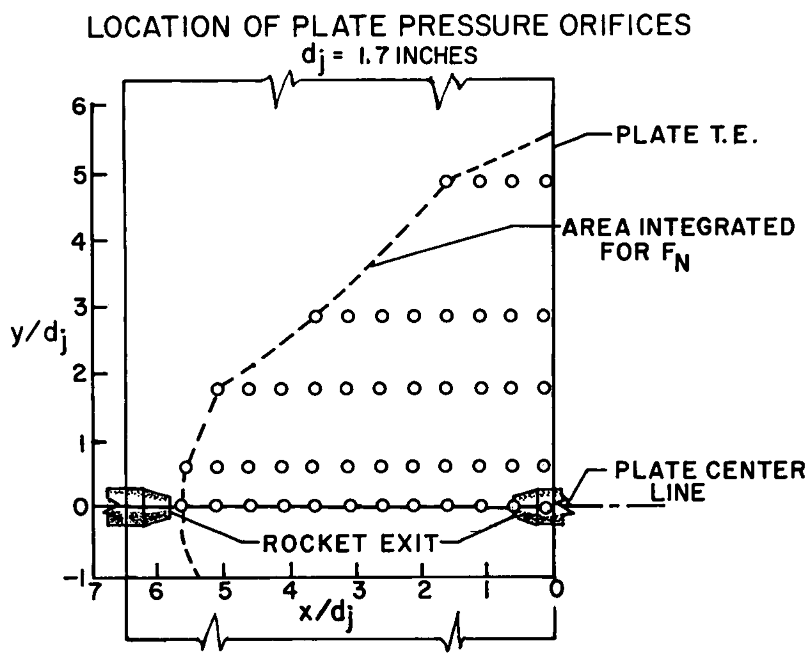

Figure 2

CENTER-LINE PRESSURE DISTRIBUTION
ROCKET EXHAUSTING DOWNSTREAM; $M_j = 3$; $p_{t,j}/p_\infty = 68$; $p_j/p_\infty = 2.1$

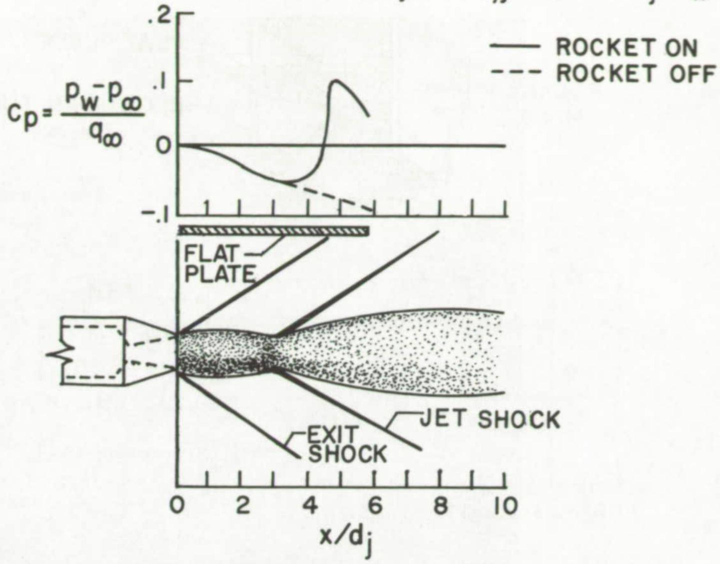

Figure 3

TYPICAL SHADOWGRAPH FOR POSITION A
ROCKET EXHAUSTING UPSTREAM

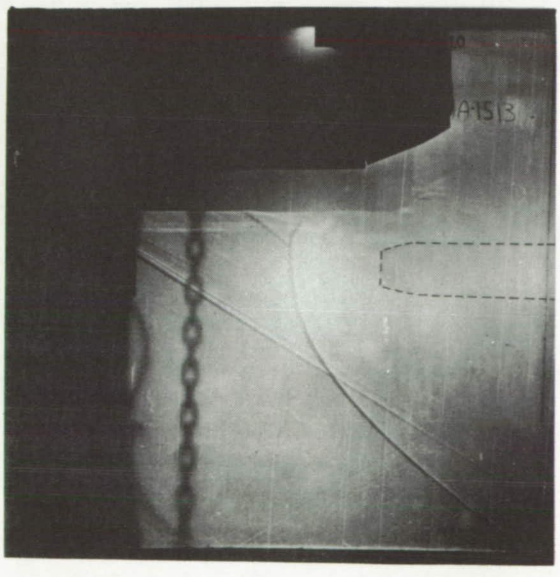

Figure 4 L-57-161

TYPICAL SHADOWGRAPH FOR POSITION C
ROCKET EXHAUSTING UPSTREAM

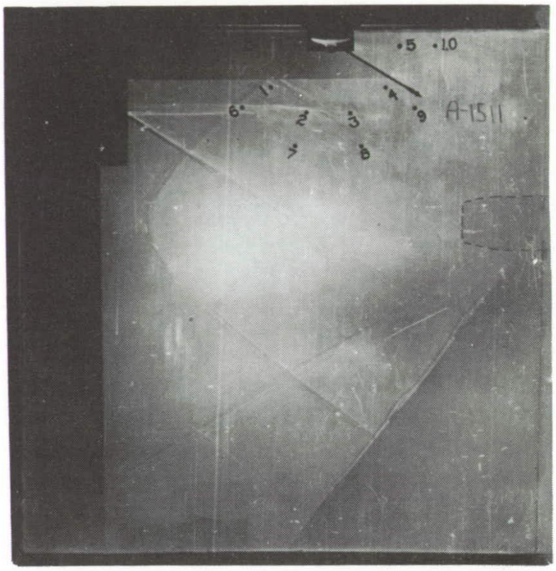

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Figure 5

CENTER-LINE PRESSURE DISTRIBUTION
ROCKET EXHAUSTING UPSTREAM; POSITION A

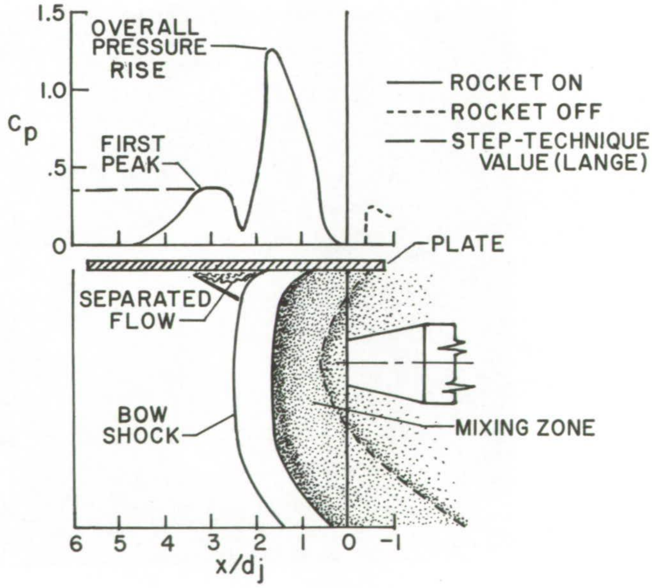

Figure 6

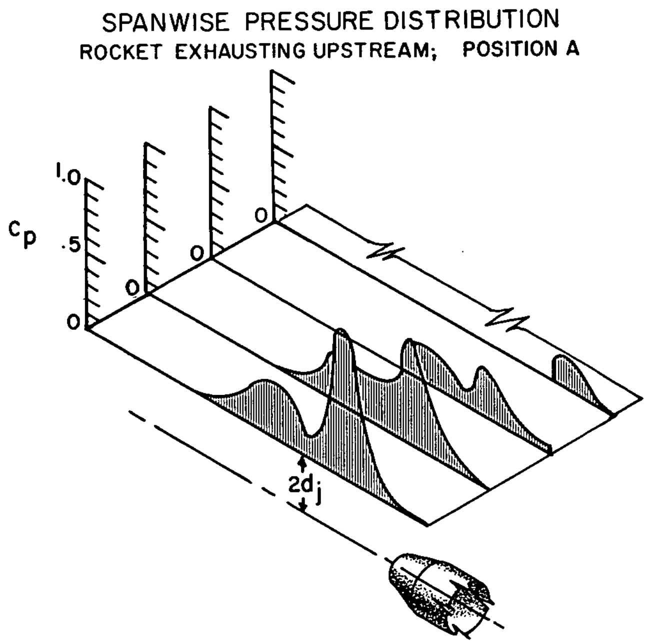

Figure 7

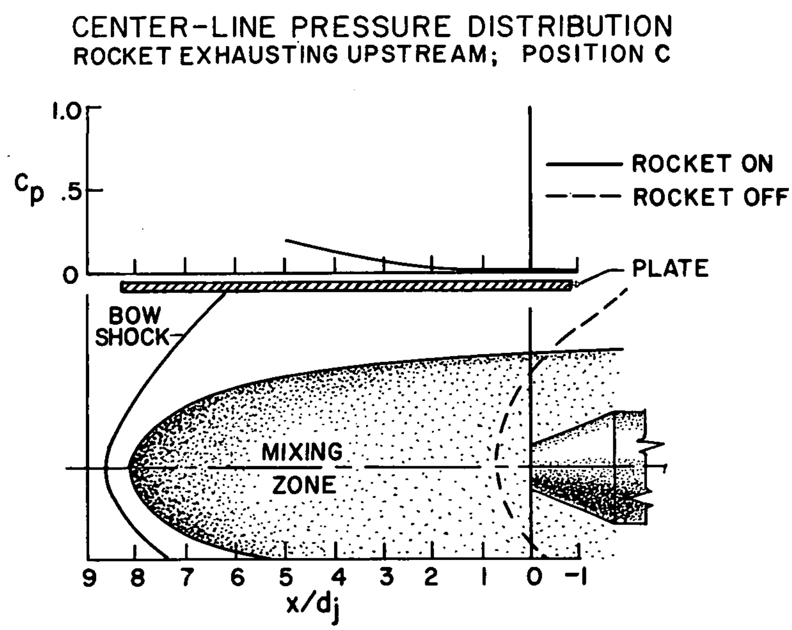

Figure 8

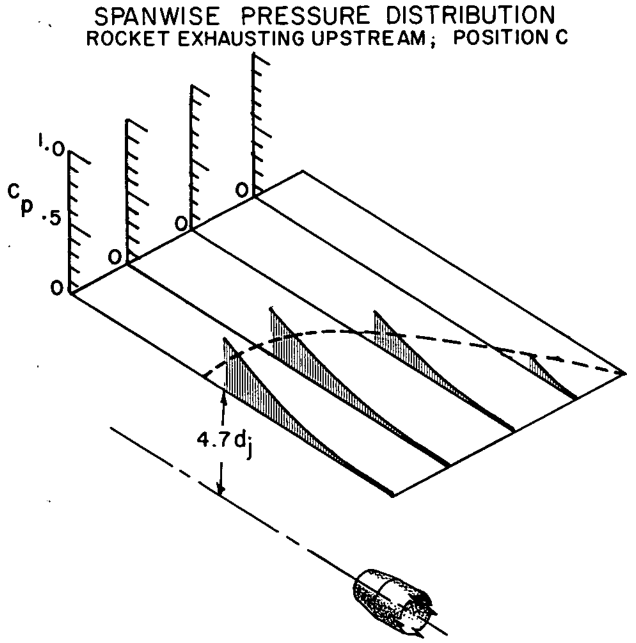

Figure 9

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